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13. ABSTRACT (Maximum 200 words)

The goal of our research was to build an ultrafast all-optical switching device in a single mode polymer optical fiber. We have concentrated on both extensive processing and characterization studies. Activities included characterizing: refractive index profile of preform slices; concentration profiles of preform slices with optical absorption; loss properties of core fibers; nonlinear refractive index of bulk and single-mode fiber with various techniques; and demonstrate an all-optical switching device in a Sagnac geometry.

We have successfully measured the loss in a single-mode fiber using the cut-and-measure technique and are applying transverse loss measurements to understand the roll of scattering in the total loss. We also characterized the refractive index profiles of preforms and found a step index as expected. The step index fiber can be made into a graded index fiber by initiating diffusion at elevated temperature. This may lead to lower loss fibers due to reduced interfacial scattering.

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refractor indexing, optical absorption, all-optical switching device, polymer optical fiber, core fibers

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# All-Optical Polymer Fiber Devices

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GRANT # F496209410337

FINAL REPORT TO AFOSR

REPORT PERIOD: 01 May 94 - 15 Aug 97

The goal of our research is to build an ultrafast all-optical switching device in a single mode polymer optical fiber. This past year, we have involved many more undergraduates in the research who have concentrated on both extensive processing and characterization studies. Activities include:

- Characterize refractive index profile of preform slices
- Characterize concentration profiles of preform slices with optical absorption
- Characterize loss properties of core fibers
- Characterize nonlinear refractive index of bulk and single-mode fiber with various techniques
- Demonstrate an all-optical switching device in a Sagnac geometry

We have successfully measured the loss in a single-mode fiber using the cut-and-measure technique and are applying transverse loss measurements to understand the roll of scattering in the total loss. We have also been characterizing the refractive index profiles of preforms and find a step index as expected. The step index fiber can be made into a graded index fiber by initiating diffusion at elevated temperature. This may lead to lower loss fibers due to reduced interfacial scattering.

We are continuing to measure the nonlinearity of several squaraine dyes in PMMA with our Sagnac interferometer experiment and have also set-up an independent bulk measurement to confirm that the numbers are real. So far, we have been able to measure a switching efficiency of about 20% in a 9mm sample of HSQ/PMMA. Given that the effective length of our single-mode fibers are between 10cm and 20cm, this material should be suitable for an all-optical switch provided that the two-photon figure of merit is low enough. We will use a new tunable laser system to find the wavelength with best figure of merit to demonstrate all-optical switching.

To summarize our cumulative research findings and results:

1. We have developed a process to make 5-10$\mu$m fiber waveguides made with PMMA/ISQ and PMMA/DR1 dye-doped polymer.
2. We have demonstrated that the guided mode is single-mode for a 8$\mu$m core at doping levels greater than 0.07% ISQ by weight.
3. We have optimized the coupling efficiency into the single-mode fiber.
4. We have found several methods for cleaving/polishing the fiber ends for better coupling.
5. We have measured the loss in the multimode PMMA/ISQ and PMMA/DR1 fiber to be equal to the neat PMMA loss (0.3dB/cm at 1.3$\mu$m and 0.1dB/cm at 1064nm).
6. We have measured the loss in a single-mode PMMA/ISQ fiber to be between 0.1dB/cm and 0.6dB/cm at 1.06$\mu$m.
7. We have determined that single-mode fibers depolarize light by less than 5%.
8. We have measured the intensity dependent refractive index in a single-mode fiber using a new Sagnac measurement developed at WSU. This experiment has also been applied to measure both the absolute real and imaginary part of the intensity dependent refractive index in nitrobenzene (a standard liquid).
9. We have found that the stimulated Brillouin scattering background signal in dye-doped polymer fiber is well below the minimum required for making a practical switch.
10. We have observed a damage threshold that is almost two orders of magnitude smaller than for neat PMMA and that it is fiber dependent.
11. We have studied the nature of excited states in squaraine dyes, and how these states contribute to the nonlinear-optical response.
12. We have successfully fabricated dual core fibers that guide light.
13. We have demonstrated a fiber directional coupler.
14. We have demonstrated all-optical switching in both a directional coupler and Sagnac geometry.

PERSONNEL SUPPORTED:

Graduate Students:
- Dennis Garvey

Note that Dennis Garvey is now writing his Ph.D. thesis and will be graduating in the summer of 1998.

Undergraduate Students:
- Chris Breckon

- Josh Clearman
- Scott Douthit
- Jeffrey Tostenrude
- Jeremy Young

Both the graduate and undergraduate students have been receiving state of the art training in interdisciplinary research and both have attended several conferences. Dennis Garvey has presented his work at several meetings and is highly regarded by the scientific community both for his work and excellent presentations.

PAPERS AND PRESENTATIONS
This work has been disseminated through several papers and presentations:

- D. W. Garvey, Q. Lin, M. G. Kuzyk, C. W. Dirk, and S. Martinez, "Sagnac interferometric intensity-dependent refractive-index measurements of polymer optical fiber," Optics Letters **21**, 435 (1996).
- D. W. Garvey, K. Zimmerman, P. Young, J. Tostenrude, J. S. Townsend, Z. Zhou, M. Lobel, M. Dayton, R. Wittorf, M. G. Kuzyk, J. Sounick, and C. W. Dirk, "Single-mode nonlinear-optical polymer fiber," Journal of the Optical Society of America **13**, 2017 (1996).
- D. W. Garvey, M. G. Kuzyk, C. W. Dirk, S. Martinez, H. Selnau Jr., P. Craig and L. Green, "Progress towards making an all-optical switch in Polymer Optical Fibers," Nonlinear Optics **15**, 104 (1996).
- C. Poga, T. M. Brown, M. G. Kuzyk, and C. W. Dirk, "Characterization of the excited states of a squaraine molecule with quadratic electroabsorption spectroscopy," J. Opt. Soc. Am. B **11**, 80 (1994).
- D. W. Garvey, R. Kruhlak, M. G. Kuzyk, C. W. Dirk, S. Martinez, H. Selnau, Jr., P. Craig, and L. Green "Characterization of Switching Properties of a Single-Mode Polymer Optical Fiber," in Nonlinear Optical Properties of Organic Materials VII, SPIE Proceedings **2527**, San Diego (1995).
- K. S. Mathis, M. G. Kuzyk, C. W. Dirk, S. Martinez, H. Selnau, Jr., P. Craig, and L. Green "Excited State Characterization of Squaraine Dye-Doped Polymers," in Nonlinear Optical Properties of Organic Materials VII, SPIE Proceedings **2527**, San Diego (1995).
- M. G. Kuzyk, "All-Optical Materials and Devices," in *Science and Technology of Organic Thin Films for Waveguiding Nonlinear Optics - Advances in Nonlinear Optics* **3**, F. Kajzar and J. D. Swalen, eds. Gordon and Breach, pp. 759-821. (invited)
- M. G. Kuzyk, Q. Li, D. J. Welker, S. Zhou, and C. W. Dirk, "All-Optical and Photomechanical Devices in Polymer Optical Fiber," SPIE OELASE'94 **2143**, (1994) (invited)
- M. G. Kuzyk, Q. Li, M. Lobel, D. J. Welker, P. Young, S. Zhou, and C. W. Dirk, "Intensity-Induced Phase Shift Phenomena in Polymer Optical Fibers," 4th IKETANI International Conference on Optically Nonlinear Organic Materials and Applications, Technical Digest, 153 (Hawaii,1994) (invited)

- M. G. Kuzyk, Q. Li, D. J. Welker, S. Zhou, and C. W. Dirk, "Applying Third-Order Field Mechanisms to a New Class of Devices," Proceedings of the First International Conference on Organic Nonlinear Optics, p76, Val Thorens, France (1994) (invited)

## TRANSITIONS

The technology developed at Washington State University is being transferred to Boston Optical Fiber. In particular, two scientists visited from BOF in early January to observe our fiber fabrication and characterization process. A central part of the drawing tower is the oven chamber. We found that fiber preforms that were made at BOF pulled into fiber better in our tower than theirs. This information is being used to redesign their system. Furthermore, we have the capabilities of measuring the refractive index profile of a preform slice. BOF has been sending samples for characterization. This information is being used as feedback to their materials processing efforts. BOF is presently funding WSU to characterize preforms and to act as a general consultant.

In addition to our ongoing collaboration with Prof. Dirk, we have also been collaborating with Prof. Stegeman.